EFFECT OF TREE WINDBREAKS AND SLAT BARRIERS ON WIND VELOCITY AND CROP YIELDS

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EFFECT OF TREE WINDBREAKS AND SLAT BARRIERS ON WIND VELOCITY AND CROP YIELDS

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Tree windbreaks have been extensively planted in the Plains section of the United States and in other parts of the world to protect farm buildings and livestock from strong winds and drifting snow, to prevent wind damage to soil and crop, and to trap snow as a source of supplemental soil moisture. They provide food and cover for wildlife and they add beauty to the rural landscape. In some States large areas of formerly treeless plains now appear well stocked with trees.

Farmstead- and livestock-protection windbreaks have been widely used by farmers and ranchers. The practice of planting tree windbreaks for soil and crop protection and to trap snow for increasing soil water for crop production has been widely accepted in some areas and rejected in others. The chief reasons for rejection are lack of sufficient rainfall to grow trees successfully, their unfavorable effect on adjacent crops in dry seasons, and the dividing of large fields into smaller ones by tree rows.

The objectives of the study were to determine (1) how tree windbreaks and barriers of different densities and orientations affect wind velocity, snow distribution, transpiration from crops, evaporation of water from soil, buildup of soil water on cropland, and crop yields and (2) what procedures might be used to correct ineffective windbreaks.

Studies with similar objectives have been carried on throughout the world for many years and a voluminous amount of literature has been published summarizing the results. However, very little of the literature applies to the northern Great Plains in the United States, which has large areas of cropland and where average rainfall seldom exceeds 14 inches per year. In areas of low rainfall, every inch of water that can be added to and retained in the soil becomes vital in producing economic crop yields.

A review of literature will not be made as several bibliographies and reviews have been issued in recent years. For research done prior to 1963, the reader is referred to a detailed and comprehensive report by Van Eimern and others (*4*).[1]

METHODS

This study was conducted at Mandan, N. Dak., and in the eastern half of this State during 1959–68. Wind velocity was measured (1) on both sides of isolated tree windbreaks of one or more rows, (2) between series of single-row tree windbreaks spaced across fields at intervals of 20 to 40 rods, and (3) on both sides of single-row slat barriers. A report (*1*) issued in 1963 summarized results to date.

One-row windbreaks had trees planted either in pure stand spaced 3 to 4 feet apart or a combination of one tree to two or three shrubs spaced 2 to 3 feet apart. Multiple-row windbreaks had shrubs spaced 2 to 3 feet apart in outside rows. Trees were planted 4 to 6 feet apart in pure stand in interior rows. Species composition varied from row to row. When these windbreaks were 5 to 10 years old, growth in the row with few exceptions became very

[1] Italic numbers in parentheses refer to Literature Cited, p. 23.

dense regardless of spacing. All rows were oriented in a north-south or east-west direction following the field crop-planting pattern.

Two noncompetitive slat barriers, each 400 feet long and 12 feet high, separated by a similar slat barrier 100 feet long and 4 feet high, were erected in a continuous northeast-southwest line at Mandan, N. Dak. The upper two-thirds of the 12-foot barriers and the entire 4-foot barrier had 42-percent density. The lower third of one 12-foot barrier had 22-percent density and the other 14 percent.

Density of windbreaks was first computed in this study by the method described by George and others (*1*) and later by estimation (fig. 1). Wind velocity at various horizontal distances expressed in terms of tree windbreak or barrier height (H)[2] was measured by anemometers, which recorded a cumulative mileage. Anemometers were located 2.5 feet above ground for most measurements. Other measurements, for comparative purposes, were made over grassland at 6.5 and 42 feet and over fallow at 0.5 and 2.5 feet. A windspeed and direction vane, located at a height of 6.5 feet, transmitted continuous data to a recorder over a 3-year period. The check area was at 40 H on the north side of the continuous slat barriers. Wind direction is referred to as originating in the north, south, east, or west side of tree windbreaks and barriers, except wind from one

[2] H refers to one unit of tree or barrier height.

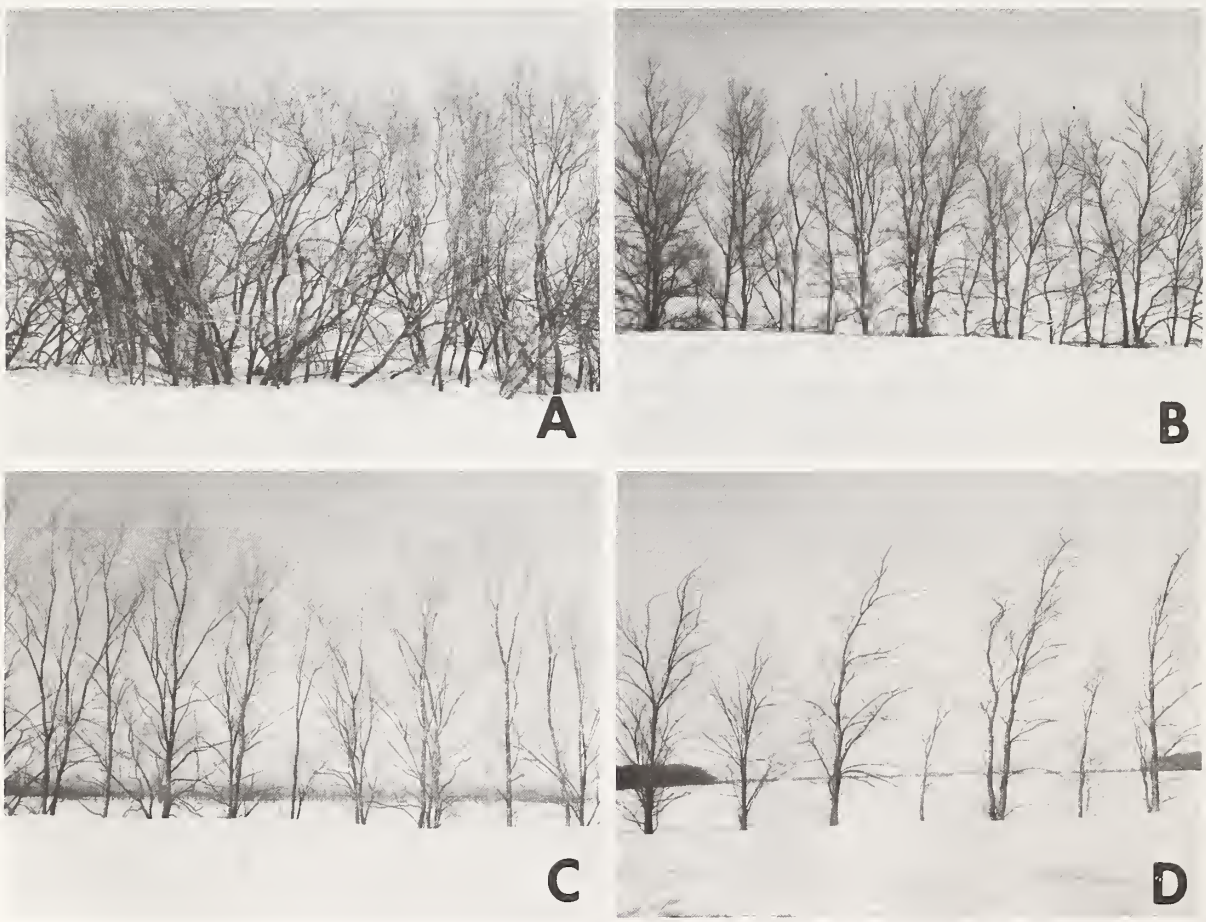

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FIGURE 1.—Estimated density of various one-row field windbreaks: *A*, Diamond willows spaced 3 feet apart—70 percent; *B*, Siberian elms 2–3 feet apart—65 percent; *C*, Siberian elms 3 feet apart—50 percent; and *D*, American elms 6 feet apart—25 percent.

specific direction only, when windward and leeward terms are used.

Data collected from isolated tree windbreaks of one or more rows and series of single rows planted at specified intervals consisted of wind velocity, snowdrift width and depth, and water content of snowdrifts in late winter. Data collected on the north and south sides of the 12-foot barrier with lower third density of 14 percent consisted of precipitation, maximum and minimum temperatures, humidity, evapotranspiration, and evaporation. Data taken on the north and south sides of both 12-foot barriers included wind velocity, snowdrift width and depth, buildup of soil water from snowdrifts, and yield of spring-planted wheat.

The relationship of wind direction to tree windbreaks was determined by snowdrift location and streamers, and for slat barriers the relationship data were taken from the nearby windspeed and direction recorder. Open wind velocity at heights of 2.5 feet in several locations and at 6.5 and 42 feet in one location was recorded daily throughout each year. Other data were recorded daily during the growing season only or for shorter periods when applicable to a particular study.

WIND VELOCITY AND DIRECTION

A knowledge of velocity and direction of erosive winds is essential when planning for soil and crop protection. Summer fallow, widely practiced in the northern Great Plains, is vulnerable from time of preparation in July through Aprii of the following year. Potato and sugarbeet fields are vulnerable from the October harvest through the following May. Soil from fall-plowed sandy fields and nonridged, bare cultivated land is blown during the winter. Snowdrifts covered with soil (fig. 2) are common during this period.

The effect of surface roughness on wind velocity near the ground has been noted by many investigators (*4, pp. 17–20*). Open wind velocity 2.5 feet above bromegrass varied widely in four scattered locations when winds did not exceed 8 miles per hour. At higher velocity the differences between locations were very small. Wind velocity 2.5 feet above ground averaged 87.8 percent of that at 6.5 feet over a 3-year period. Over an 18-month period, velocity at 2.5 and 6.5 feet averaged 53 and 64 percent, respectively, of that at 42 feet.

Wind velocity over bromegrass and duckfoot fallow at a height of 2.5 feet was identicai when averaged over a 12-month period. It was 10 percent greater over fallow during the snow-free period and 10 percent less when snow was trapped in the grass. The fallow seldom held any snow cover in contrast to the smoother surface given the grass by trapped snow. Over fallow, wind velocity at a height of 0.5 foot averaged 51 percent of that at 2.5 feet.

Figure 3 shows the maximum velocity and wind direction at Mandan, N. Dak., during 1966–67. Calm periods in each month varied

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FIGURE 2.—This 4- to 6-inch layer of soil came from fall-plowed field on north side of a one-row east-west windbreak. As an insulator, it delayed melting of this 80-foot-wide snowdrift.

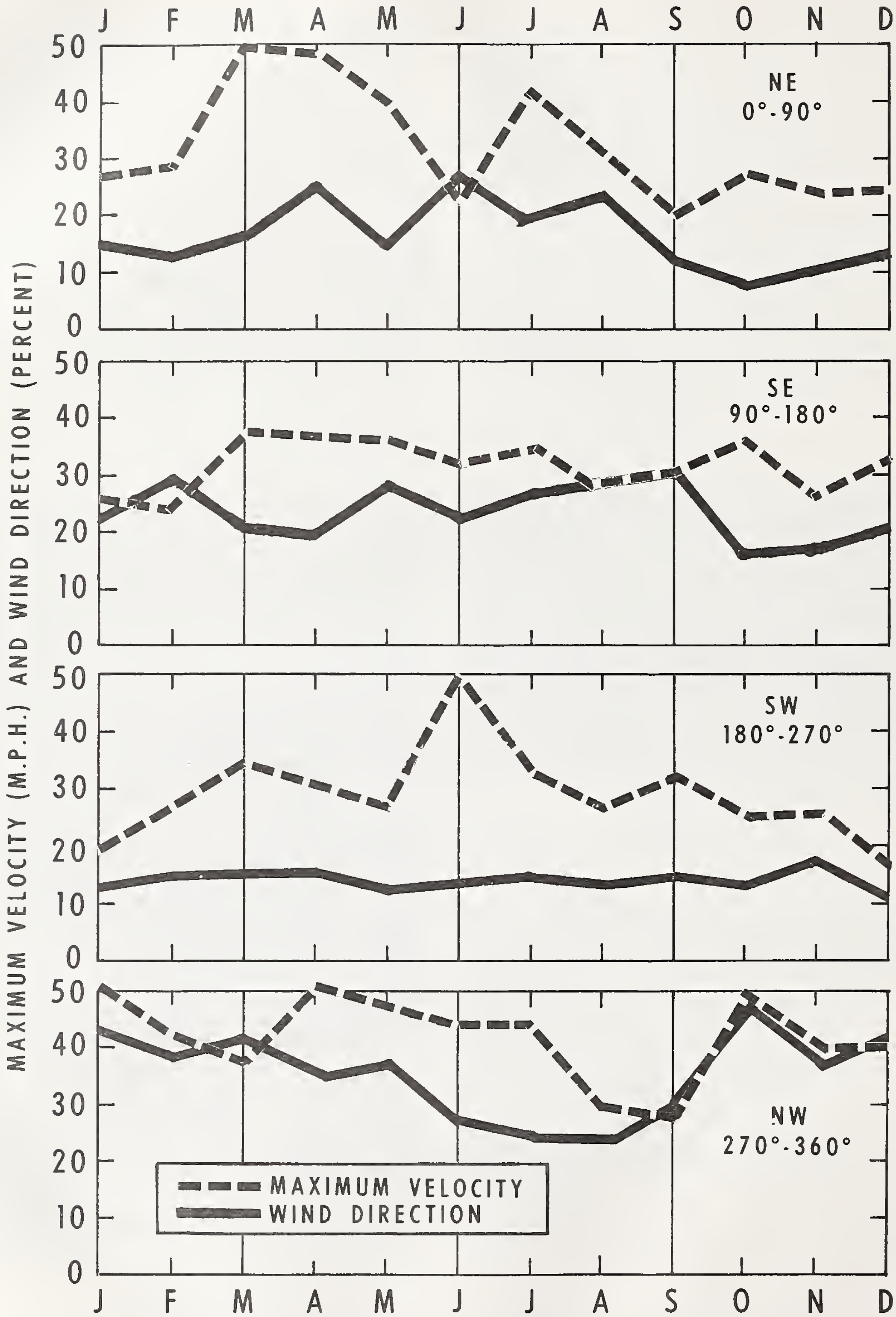

FIGURE 3.—Maximum monthly velocity and wind direction from January 1, 1966, to December 31, 1967, at Mandan, N. Dak.

from 3 to 5 percent in February, March, and April to 11 percent in September and December.

The northwest wind was the source of most wind velocity followed in order by the southeast, northeast, and southwest. The highest maximum monthly velocity was from the northwest, with winds recorded at 40 to 50 miles per hour every month from October through July. Bare land, unless ridged by duckfoot cultivation, is subject to blowing by erosive winds from all directions, especially the northwest. Fall ridging in a northeast-southwest direction by duckfoot cultivation to prevent or lessen erosion by northwest winds is becoming a common farming practice. High-velocity winds from the other three directions occurred during March, April, and May. Cultivated land has little protective ground cover during these months and much of the fall-roughened land has become smooth from continuous wind action. High June winds occur when fields normally have a good ground cover.

Wind-direction data show that winds seldom blow from due north, south, east, or west. Snowdrift streamers usually run at an angle of 45° or less to the windbreaks. East-west windbreaks gave wider snow distribution and of less depth than did north-south ones, indicating more northwest winds of high velocity originated in an arc of 315° to 360° than in one of 270° to 315°. Several investigators (*4, pp. 23–25*) have shown that as the angle of incidence between wind direction and windbreak orientation decreases, the protected area on the leeward side also decreases. However, snowdrift patterns show that as the windbreak density increases, it results in narrow, deep snowdrifts as contrasted with wide, more shallow drifts formed by winds striking the windbreak at an angle approaching 90°.

High-velocity winds were not static in either speed or direction. They changed constantly, ranging over a high and low speed and differing by 20 or more miles per hour. Direction differences ranged over an arc of 90° or more. As winds decreased, variations in speed and direction decreased. The constant changing of speed and direction of high-velocity winds results in frequent change of branch position in tree windbreaks, which increases or decreases the branches' protective ability.

WIND REDUCTION

Tree Windbreaks

Many investigators have reported that tree windbreak height, density, and orientation to prevailing winds govern the distance and effectiveness of wind reduction on the leeward side (*4, pp. 5–12, 22*). When series of one-row windbreaks having trees or shrubs of different species, heights, and densities are spaced across fields at similar intervals, the wind-reduction pattern will vary on the leeward side of each row of different species. Wind reduction is also affected by the ground cover when it differs from field to field.

Figure 4 shows how species of different kinds and growth rates in a series of seven one-row east-west windbreaks, 20 rods apart, affected wind reduction. Velocity was measured of winds originating in the northwest and southeast at 2.5 feet above ground. Anemometers were located at 7 and 13 rods between each windbreak.

The row order from north to south was Siberian elm (*Ulmus pumila* L.), 18 feet high, spaced 3 to 4 feet apart in rows 1, 3, 5, and 7; Siberian peashrub (*Caragana arborescens* Lam.), 6 feet high, alternated with green ash (*Fraxinus pennsylvanica* Marsh.), 9 feet high, and spaced 2 feet apart in rows 2 and 6; and Siberian peashrub, 6 feet high, alternated with American elm (*Ulmus americana* L.), 9 feet high, and spaced 2 feet apart in row 4. Siberian elm and Siberian peashrub had 95-percent or more survival. Green ash and American elm stands had less than 10-percent survival, which made the Siberian peashrub rows almost pure stands of that species spaced 4 feet apart.

Wind velocity was measured during the summer when trees were in full leaf and had their maximum density. Open wind velocity of the two opposite winds varied less than 2 miles per hour. Wind reduction on the leeward side of all Siberian elm rows at 7 rods (6 H) was 50

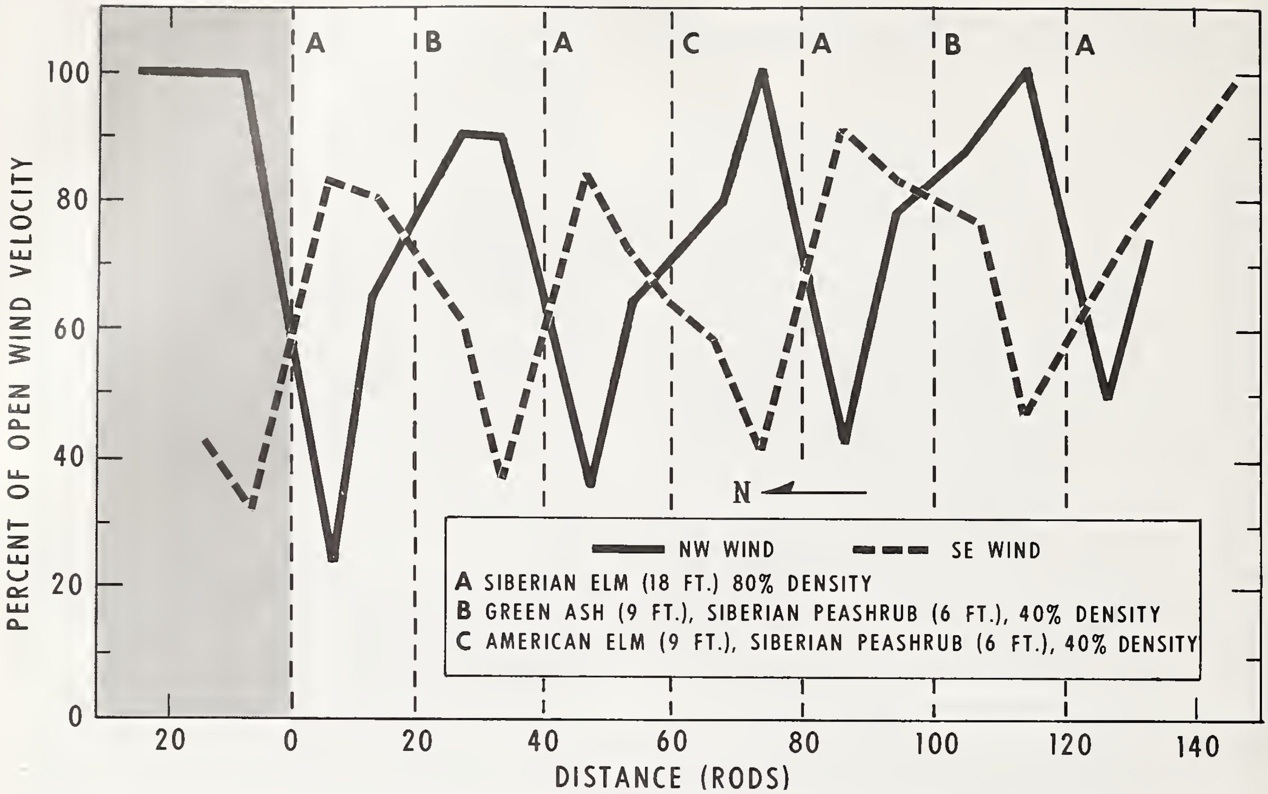

FIGURE 4.—Reduction of winds originating in northwest and southeast by series of seven one-row east-west windbreaks with different species and growth rates and spaced 20 rods apart. Each field between windbreaks had two types of ground cover.

percent or more and showed differences of less than 7 percent between the opposite winds. Differences between opposite winds on the leeward side of the combination green ash- or American elm-Siberian peashrub rows at 7 rods (19 H) varied from 10 to 22 percent. Greater protection was offered against winds originating in the southeast than those in the northwest. However, the maximum reduction did not exceed 30 percent as contrasted with reductions up to 65 percent at 7 rods on the leeward side of Siberian elm rows.

Wind velocity at 13 rods showed greater differences between opposite winds. None of the northwest wind reductions were sufficient to reduce strong erosive winds to nonerosive rates. Neither did they show a cumulative reduction effect as they proceeded downwind across the field (*4, p. 25*). Winds originating in the southeast tended to show a cumulative reduction, which was sufficient to reduce winds of 25 miles per hour to nonerosive rates on the leeward side of Siberian elm rows at 13 rods (12 H). The wind reduction on the leeward side of Siberian peashrub rows at 13 rods (36 H) was less than 20 percent.

Ground cover was in part responsible for the greater differences at 13 rods between winds from opposite directions (*4, pp. 17–20*). Each 20-rod strip between windbreaks was planted to two crops of 10 rods each using combinations of corn, oats, potatoes, or alfalfa. Smooth potato land in the 7-rod area with second-growth alfalfa in the 13-rod area was much more effective in reducing wind velocity from one direction than when wind direction was reversed and the smooth potato land was in the 13-rod strip. When alfalfa or oat stubble was in the 13-rod strip, it was much more effective in reducing wind velocity than was the smooth potato land or very short corn stubble.

Figure 5 shows winter wind velocity, expressed as percent of open northwest wind, between a series of five one-row north-south windbreaks spaced 20 rods apart. Siberian elm, 16 feet high, was spaced 3 to 4 feet apart in rows 1, 3, and 5 in order of windward to leeward. The rows had a density of 55-60 percent. Snowdrifts 1 to 2 feet deep and 20 to 30 feet wide were present on the leeward side of each row. Russian-olive (*Elaeagnus angustifolia* L.), 7 feet high, was spaced 3 feet apart in row 2. Its density was 65 percent, which was increased by a snowdrift, 5 feet deep in the row, that extended leeward for 15 feet. An American elm-Siberian peashrub combination, 9 and 6 feet high, respectively, was spaced 2 feet apart in row 4. Its average density was 35 percent. A snowdrift 3 feet in the row extended leeward for 15 feet. Snowdrifts 9 inches deep were present on the windward side of all rows. The fields between windbreaks had a 9-inch snow depth in the stubble.

Anemometers were installed at 5-, 10-, and 15-rod intervals between each 20-rod row. Siberian elm was the tallest and most effective species in reducing wind velocity. Reductions on its leeward side were 40 percent or more at 5 and 10 rods (5 and 10 H) and from 22 to 32 percent at 15 rods (15 H). The reductions at 5 and 10 rods were enough to change an erosive wind of 25 miles per hour to a nonerosive rate.

The American elm-Siberian peashrub combination gave wind reductions of 20, 15, and 12 percent at 5, 10, and 15 rods (10, 20, and 30 H), respectively. The Russian-olive row with the highest normal density, which was increased in the lower part to 100 percent by the snowdrift, showed indications of wind turbulence at 5 rods (12 H), where the velocity was 103 percent. However, at 10 and 15 rods, the open wind velocity was reduced by 20 percent. The wind-reduction data in this series again emphasize the advantage of using tall species that do not develop more than a medium density.

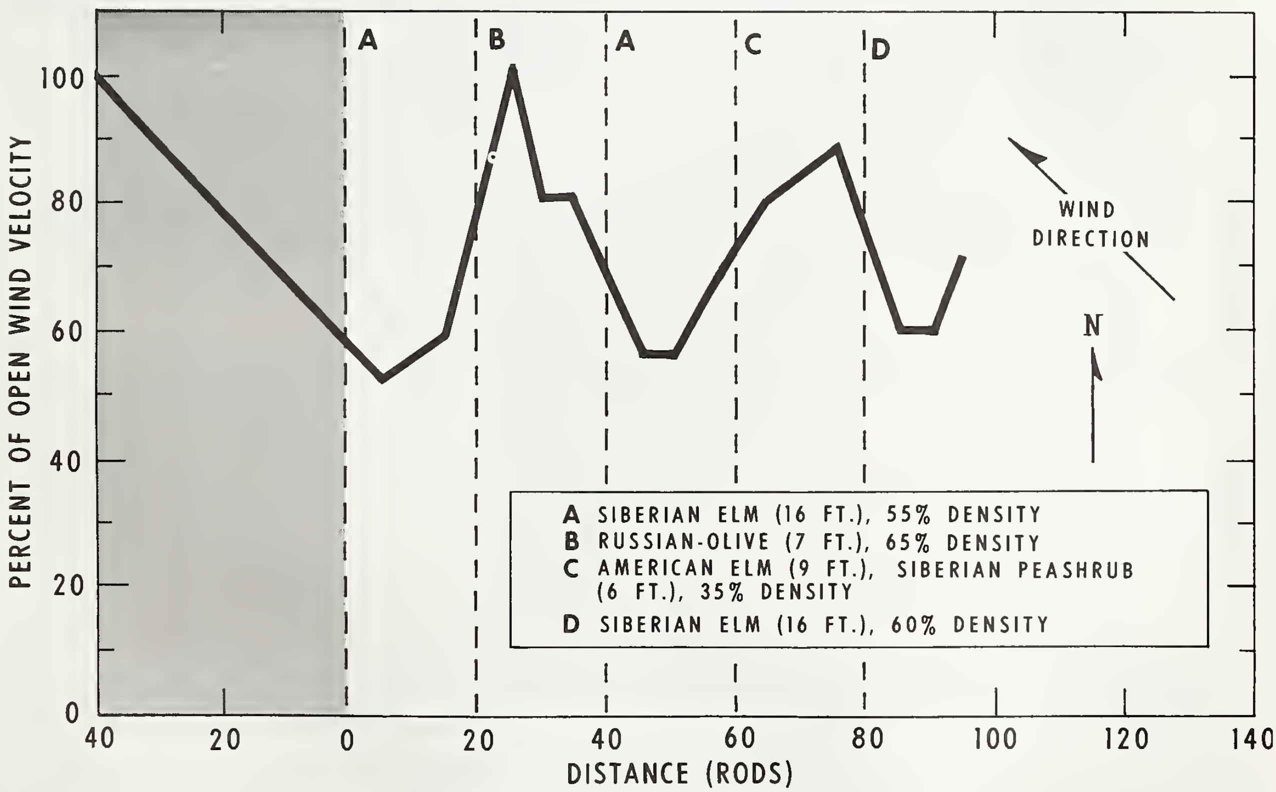

FIGURE 5.—Northwest wind velocity, expressed as percent of open wind, between series of one-row north-south windbreaks spaced 20 rods apart. All fields between windbreaks had similar ground cover.

Slat Barriers

Slat barriers maintain a more uniform density against strong winds than do tree windbreaks. The average wind velocity was measured at various locations on the north and south sides of a northeast-southwest slat barrier, 400 feet long and 12 feet high, with lower third and upper two-thirds density of 14 and 42 percent, respectively. Variable winds originated in all directions during the year.

In figure 6, measurement of variable-direction winds shows that the average wind reduction at any location was less than 20 percent. Although these data do not show the effect of a barrier on reducing wind velocity from one direction only, they do indicate that series of windbreaks would be necessary if soil and crop are to be protected from wind damage.

Figure 7 shows how a slat barrier, 12 feet high with lower third and upper two-thirds density of 14 and 42 percent, respectively, reduced winds that originated in specific directions. Anemometers were placed at 5, 7.5, 10, 15, and 20 H on the north side and at 5, 10, 15, 20, 25, and 30 H on the south side.

Windward velocity of all winds differed only slightly from the check (40 H) regardless of origin. Leeward velocity of all winds was also similar and showed a maximum reduction of 40 to 46 percent at 5 to 7.5 H. This reduction rapidly decreased to 20 percent at 15 H and to less than 10 percent at 20 H.

The data show that the barrier offered the same approximate resistance to wind regardless of its direction. Barrier density did not change with wind direction as do tree branches in peri-

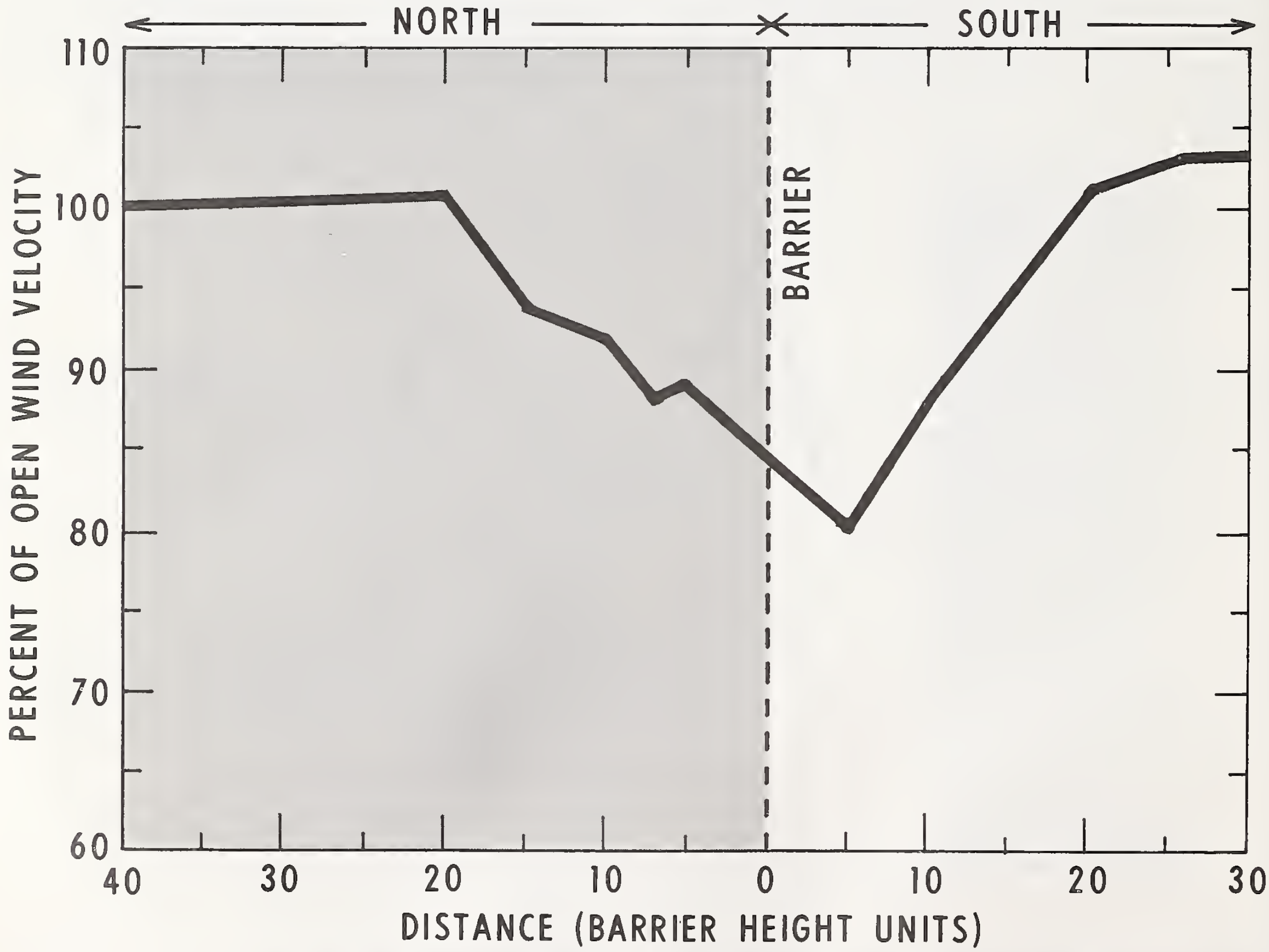

FIGURE 6.—Average wind velocity over 3-year period on north and south sides of northeast-southwest slat barrier when 55 percent of wind originated on north side and 45 percent on south side in arcs of 225°–45° and 45°–225°, respectively.

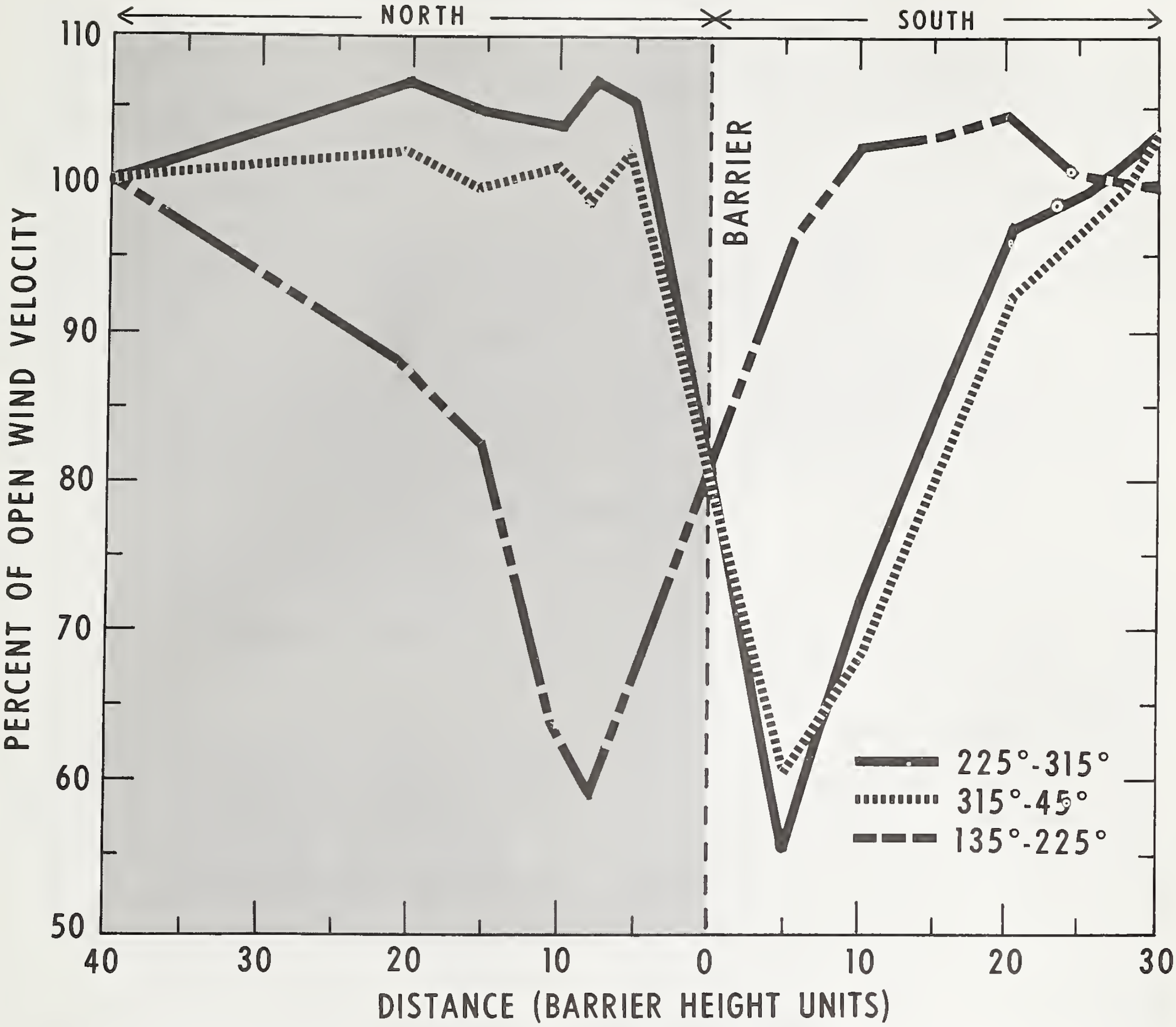

FIGURE 7.—Average wind velocity on north and south sides of northeast-southwest slat barrier when winds originated in arcs of 225°–315° and 315°–45° on north side and 135°–225° on south side.

ods of high or gusty winds. Tree density also is changed by leaf growth in the spring and leaf loss in the fall.

Table 1 compares the wind velocity on the windward and leeward sides of three slat barriers 12 feet high with density in upper two-thirds of 42 percent and in lower third of 42, 22, and 14 percent. The northwest wind ranged up to 15–20 m.p.h. and up to 30° in direction on either side of a 90° angle to the barrier. The barriers were oriented in a continuous northeast-southwest line with the 42-percent barrier in the center.

Windward velocity showed no appreciable reduction at any location and only small differences between the three barriers. On the leeward side at 5 H, the 42-percent barrier reduced wind velocity 17 percent more than the 14-percent barrier. Differences at 10 H were small and almost identical beyond that point.

None of the barriers beyond 10 H reduced wind velocity enough to change an erosive wind to a nonerosive one. Although the highest density barrier showed the greatest reduction at 5 H, the area of increased reduction is possibly too small to warrant the use of barriers with such high lower third densities. These latter barriers create other problems.

TABLE 1.—*Wind velocity at various locations on windward and leeward sides of 3 slat barriers of various densities when northwest wind 2.5 feet above ground was up to 15–20 m.p.h. and up to 30° in direction on either side of 90° angle to barrier*

Density of lower third barrier (percent) [1]	Velocity[2] at indicated locations									
	Windward					Leeward				
	20 H	15 H	10 H	7.5 H	5 H	5 H	10 H	15 H	20 H	30 H
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
42	93	97	94	94	89	41	57	73	82	89
22	96	96	95	93	93	55	61	74	80	89
14	96	94	96	95	94	58	59	73	80	89

[1] Upper 2/3 density = 42 percent.
[2] Expressed as percent of open wind; check =100 percent.

WIND BEHAVIOR

Neither the 14- or 22-percent barrier gave any evidence of the wind turbulence on its leeward side that had been observed on the leeward side of higher density tree windbreaks. Many investigators (*4, p. 10*) have shown that dense shelterbelts produce turbulence and reverse wind direction on their leeward side. They also have found that wind velocity increased in shorter distances on the leeward side of dense shelterbelts. Others (*4, pp. 11–13*) have shown that velocity of turbulent winds cannot be measured accurately. Hetzler and others (*2*) have found in wind-tunnel studies that velocity could not be measured accurately when wind struck the anemometer at an angle of more than 30°. The anemometers ceased to rotate at an angle of 70°, and they had a negative rotation when the angle was between 70° and 90°.

Wind behavior as related to direction on the leeward side of a dense barrier was studied by placing a 4-foot canvas along the bottom of a slat barrier 12 feet high and 400 feet long. The upper two-thirds density was 42 percent. Wire frames, 12 feet wide and 18 feet high with ribbon streamers at 1-foot vertical and horizontal intervals, were installed at leeward locations of 2.5 and 5 H and similar frames 12 by 12 feet at 7.5, 10, and 15 H.

Table 2 shows wind direction on the leeward side of a barrier with a lower third density of 100 percent. Wind direction was reversed up to heights of 10, 8, and 4 feet at 2.5, 5, and 7.5 H, respectively. Swirling wind action (N+S) from 11 to 18 feet was noted at 2.5 H only. The wind resumed its normal flow direction at 10 H.

TABLE 2.—*Wind direction at various heights and locations on leeward side of slat barrier with lower third density of 100 percent when wind was blowing in southeast direction at windward 40 H*

Height (feet)	Wind direction at—				
	2.5 H	5 H	7.5 H	10 H	15 H
18	N+S	SE	----	----	----
17	N+S	SE	----	----	----
16	N+S	SE	----	----	----
15	N+S	SE	----	----	----
14	N+S	SE	----	----	----
13	N+S	SE	----	----	----
12	N+S	SE	SE	SE	SE
11	N+S	SE	SE	SE	SE
10	NW	SE	SE	SE	SE
9	NW	SE	SE	SE	SE
8	NW	NW	SE	SE	SE
7	NW	NW	SE	SE	SE
6	NW	NW	SE	SE	SE
5	NW	NW	SE	SE	SE
4	NW	NW	NW	SE	SE
3	NW	NW	NW	SE	SE
2	NW	NW	NW	SE	SE
1	NW	NW	NW	SE	SE

SNOWDRIFTS

Windbreak height and density affect snow deposits on adjacent land (*4, pp. 59–64*). Windbreaks of identical species, age, spacing, and orientation form similar snowdrift patterns, whereas those of different species and spacing make very different patterns.

Figure 8 shows snowdrift patterns formed by a series of one-row north-south and east-west windbreaks of identical species, age, and spacing. North-south windbreaks in area "A" were 20 rods apart on land that sloped sharply to the south and more gently to the east. East-west windbreaks in area "B" were 40 rods apart on land that sloped to the south in the northern half and was level to gently rolling in the southern half. Similar east-west windbreaks were planted in the section to the south of "B" and north-south ones immediately east of both areas. Tree height varied less than 2 feet. Ground cover between windbreaks was wheat stubble with a 4-inch snow cover or bare fallow. Snowdrift depths shown were present on March 2, 1967, when the snow density averaged 40-percent water content. No thawing had occurred previously.

Snowdrifts were formed mainly by northwest winds. The north-south rows in area "A" had deeper, narrower drifts than did the east-west rows on adjacent land to the south. The drifts in each area showed small variation in snow depth but very little difference in width, indicating no evidence of a cumulative wind

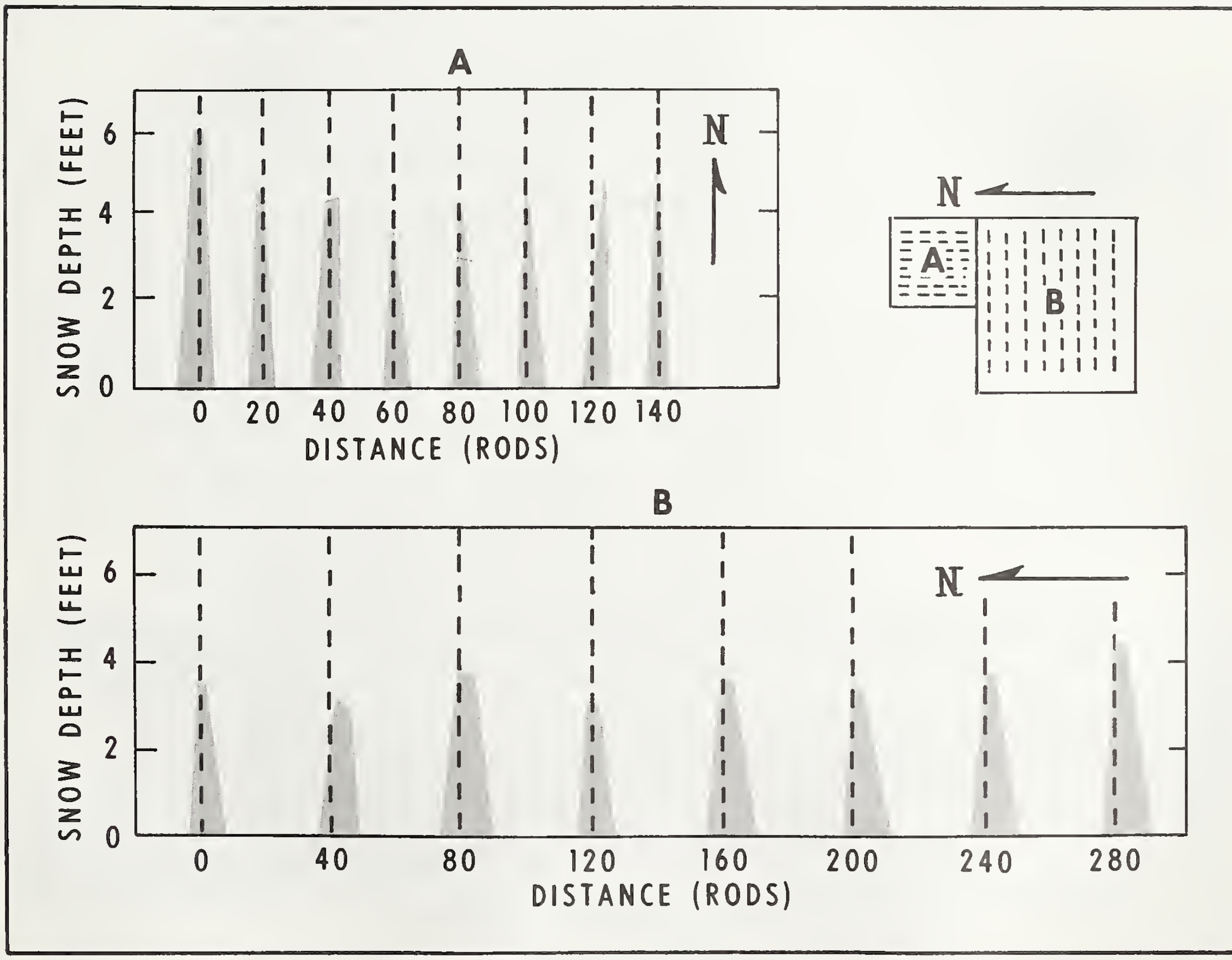

FIGURE 8.—Snowdrifts formed by series of one-row north-south and east-west windbreaks of same species, age, and spacing.

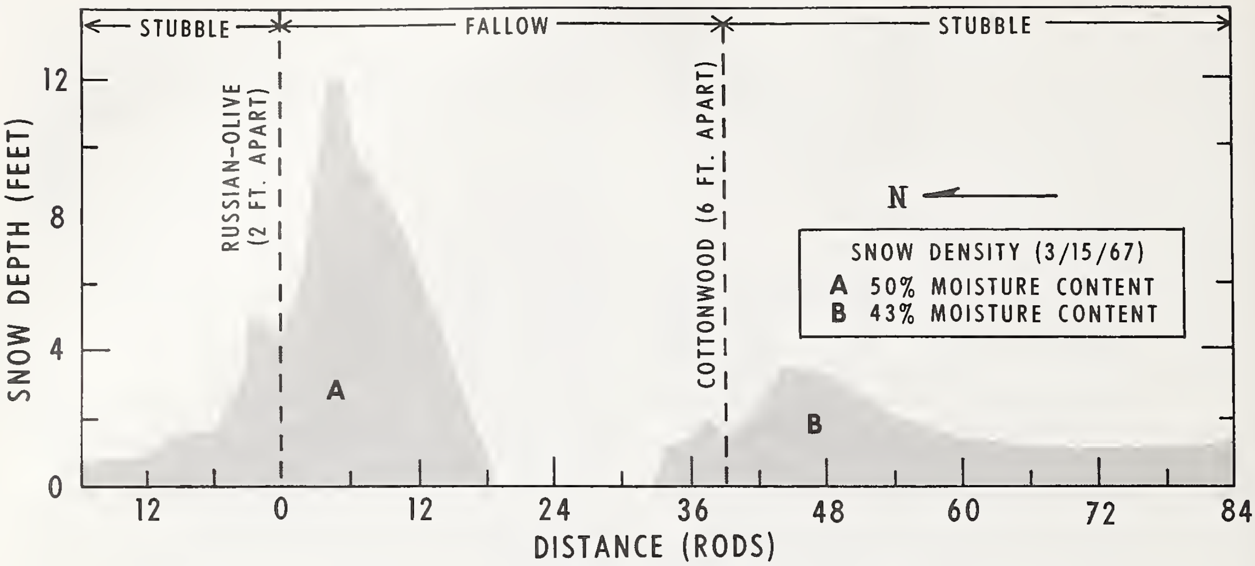

FIGURE 9.—Snowdrifts formed by two one-row east-west windbreaks of different species, growth forms, and spacing.

reduction or snow-trapping power. Each windbreak acted as a separate entity in trapping snow, which possibly would have changed very little if the windbreaks had been spaced farther apart.

Figure 9 shows snowdrifts formed by two one-row east-west windbreaks spaced 40 rods apart with different species and spacing. The high density of the closely spaced Russian-olive gave a deep, hard-packed snowdrift, which had a 50-percent water content. Cottonwood trees (*Populus sargentii* Dode) in the other row were spaced farther apart and developed a more open form of growth. They gave a snowdrift of less depth and greater width, which benefited a greater area of cropland, reduced the water-erosion hazard, and made earlier farming possible in the spring.

High-density windbreaks that trap deep snowdrifts on their leeward side create the wind turbulence previously described. Figure 10 shows how wind turbulence removed all snow from cultivated land that had no protective ground cover. The land was on the immediate leeward side of a snowdrift, 18 feet deep and 50 feet wide, which was formed by a three-row east-west tree windbreak, 24 feet high, during a 4-day storm. The snowfall totaled 33 inches and was accompanied by high-velocity north-northeast to north-northwest winds during the entire period. The picture was taken 6 hours after the wind and snow had ceased.

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FIGURE 10.—Wind turbulence, caused by 100-percent density of three-row tree windbreak and deep snowdrift, removed entire 33-inch snowfall from plowed land on immediate leeward side.

OTHER CLIMATOLOGICAL FACTORS

Precipitation

Standard Weather Bureau rain gages were used to measure precipitation at 40 H on the north side (check) and at 5 H on the south side of a 12-foot slat barrier. Records taken over a 3-year period show no differences except those that could be traced to snow blowing on the south side (*4, pp. 57–59*).

Temperature and Humidity

Maximum and minimum thermometers installed in the check area and at 5 H on the south side of the barrier showed differences only infrequently. The maximum difference on each kind of thermometer never exceeded 2°, and when such occurred, the highest maximum and lowest minimum temperatures were always on the south side (*4, pp. 42–48*).

Humidity was measured only during the growing season by installing recording hygrothermographs in the check area and at 2.5, 5, 10, 15, and 20 H on the south side of the barrier. Figure 11 shows differences were minor and indicated the barrier had little effect on temperature and humidity. Some investigators (*4, pp. 51–55*) found that small humidity differences during the late evening and early morning appeared to be associated with barrier density, whereby the relative humidity increased nearer the barrier as a result of wind reduction and more soil moisture.

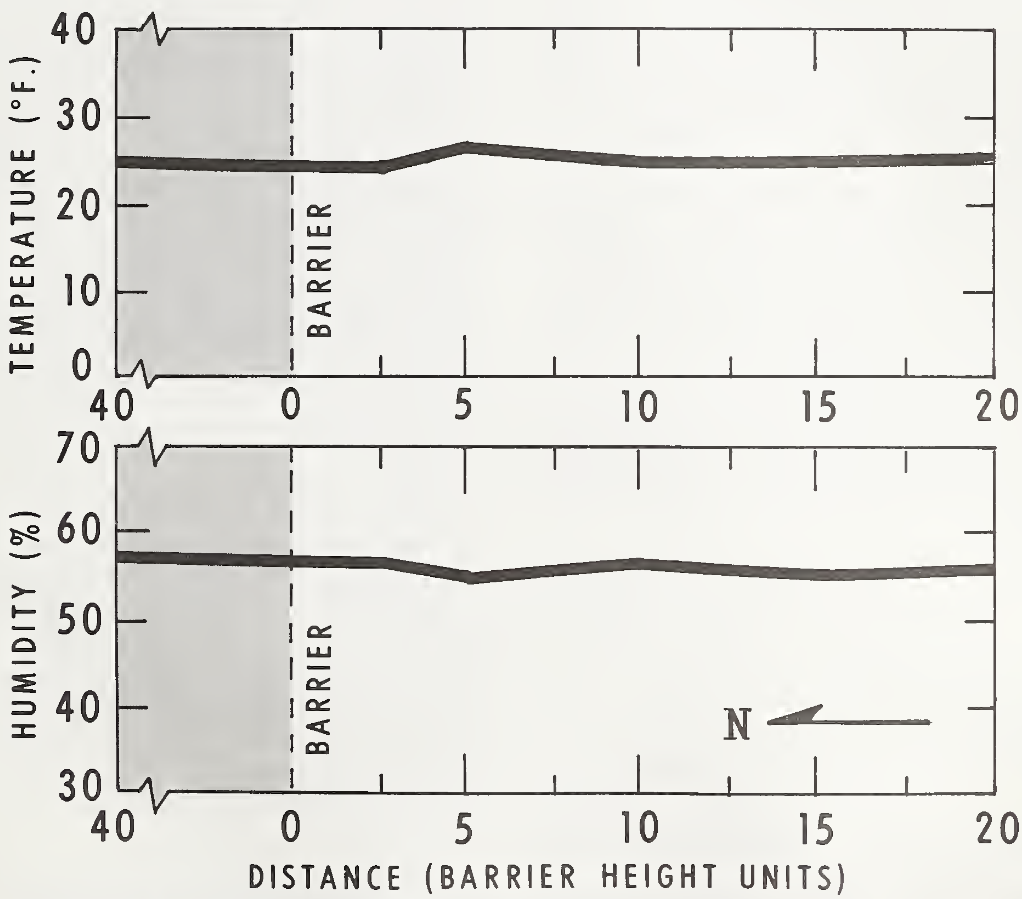

FIGURE 11.—Differences in yearly temperature and seasonal humidity on north (check) and south sides of 12-foot slat barrier.

Evapotranspiration and Evaporation

Methods to reduce evapotranspiration from crops and evaporation from soil are necessary conservation practices in semiarid regions. The effect of windbreaks on these factors has been studied and reported by many investigators with variable results (*4, pp. 64–69*). A study was made of the effect of a salt barrier on reducing evapotranspiration. Lysimeter tanks were installed at 40 H on the north side (check) and at 3.5, 7.5, 10, and 15 H on the south side of the barrier.

Lysimeter tanks, 3.5 feet cubed, were filled with uniformly mixed soil and placed on coiled rubber tubes filled with liquid. They were put inside larger buried tanks that had their tops protruding above ground. The space between tanks was sealed to prevent entrance of precipitation. The coiled rubber tubes were connected by copper lines to manometer boards. Similar dummy copper lines running parallel to the tank lines were used to measure temperature expansion or contraction of the liquid.

Bromegrass was grown in the tanks to measure the evapotranspiration loss. It was clipped frequently in 1967 and the early part of 1968 to maintain a ground cover similar to that of the surrounding terrain. It was left uncut in the last part of 1968. Tank readings were taken daily throughout the year.

Table 3 shows precipitation and snowdrift gains and evapotranspiration and evaporation losses from the lysimeter tanks during four periods in 1967 and 1968, which are described as follows:

Jan. 1–May 13, 1967 ___Heavy drifting snowfall, including last snowfall in spring.
May 14–Oct. 26, 1967 __Growing season; rain.
Oct. 27, 1967–Apr. 25, 1968 _______Plants dormant; rain, snow, drifting snow.
Apr. 26–Sept. 30, 1968__Growing season; rain.

During the two winter periods, all tanks showed water gains greater than the precipitation. The increased gains were due to snowdrifts on the tanks. Tanks at 3.5 and 7.5 H were in the general snowdrift area, which had gains and losses from the top of the snowdrift area only. Those at 40, 10, and 15 H were outside the main snowdrift area, where drifting snow was constantly being moved on and off by the wind. Water losses at 3.5 and 7.5 H during the winter may be traced to evaporation and sublimation of the snowdrift and by minor runoff. Losses at the other locations were also due to these factors, except runoff and removal of snow by wind.

During the growing season, when all precipitation was rain, gains were more closely related to precipitation than those during the winter, but do show some variation. Differences can only be traced to evaporation from the grass of light rains that fell between the 24-hour reading periods. Greater losses from that source occurred in the last part of 1968, when the grass was not cut and thus the surface could retain the rainfall for later evapotranspiration.

Water losses from all tanks on the south side of the barrier were greater than the check during both growing seasons. The order of loss was not the same in both seasons, with the tank at 7.5 H showing the least in 1967 and the greatest in 1968. The greater wind reduction at 5 H as compared with that at 10 and 15 H had no effect on decreasing evapotranspiration at 3.5 and 7.5 H when compared with losses at 10 and 15 H. Neither did the reduced wind on the leeward side have any effect on reducing evapotranspiration as compared with that of the check, which had no wind protection.

Published data (*4, pp. 64–65*) show that shelterbelts reduced evaporation considerably when evaporimeters were used to measure losses, but the reduction was considerably less than that of the wind. Other investigators (*4, p. 66*) have shown that evaporation measured with evaporimeters is, to a large extent, proportional to the root of the windspeed. However, vapor pressure and temperature of the evaporated surfaces must remain constant for that factor to function.

Free-water tanks similar in size to the lysimeter tanks but only half as deep were installed in 1967 adjacent to the check and to the south-side lysimeter tanks at 3.5 and 7.5 H.

TABLE 3.—*Precipitation and snowdrift gains, evapotranspiration and evaporation losses, wind velocity, and precipitation when lysimeter tanks were installed at various locations on north (40 H) and south (3.5–15 H) sides of slat barrier during 1967–68*

Period	Data when lysimeter tanks were installed at—														Precipitation
	40 H (check)			3.5 H			7.5 H		10 H			15 H			
	Gain	Loss	Wind velocity	Gain	Loss	Wind velocity[1]	Gain	Loss	Gain	Loss	Wind velocity	Gain	Loss	Wind velocity	
	Inches	*Inches*	*Percent*	*Inches*	*Inches*	*Percent*	*Inches*	*Inches*	*Inches*	*Inches*	*Percent*	*Inches*	*Inches*	*Percent*	*Inches*
Jan. 1–May 13, 1967	13.4	8.4	100	24.8	18.6	55	32.1	25.8	14.9	11.5	59	12.9	8.0	61	4.15
May 14–Oct. 26, 1967	10.4	9.7	100	9.8	12.5	85	9.7	10.8	9.3	11.6	96	10.3	11.6	98	9.92
Oct. 27, 1967–Apr. 25, 1968.	8.4	6.5	100	27.4	27.1	75	22.5	19.2	6.6	6.1	77	7.4	6.8	88	3.19
Apr. 26–Sept. 30, 1968	10.8	14.9	100	10.8	16.7	78	10.8	17.0	11.8	15.4	94	10.8	15.0	95	13.97
Total	43.0	39.5	-------	72.8	74.9	-------	75.1	72.8	42.6	44.6	-------	41.4	41.4	-------	31.23
Gain or loss	3.5	0	-------	0	2.1	-------	2.3	0	0	2.0	-------	0	0	-------	-------

[1] At 5 H.

Three additional tanks were installed in 1968 adjacent to lysimeter tanks at 10, 15, and 20 H. The latter tanks extended to 15 H only. Readings were taken daily from September 9 to October 26, 1967, and from April 26 to September 30, 1968.

Evaporation and evapotranspiration losses for each period are compared in table 4. Evaporation losses with one exception were less and the evapotranspiration losses were more than the respective checks in both years. The free-water tank at 15 H showed a loss of 0.6 inch more than the check in 1968. Previously the barrier had no effect on reducing the evapotranspiration loss on its south side. However, it did reduce evaporation of free water on its south side. The least water loss was at 3.5 H and the 1968 data show an increasing loss trend as distance increased from the barrier to 15 H,

TABLE 4.—*Evaporation losses from free-water tanks and evapotranspiration from bromegrass in adjacent lysimeter tanks at various locations on north (40 H) and south (3.5–20 H) sides of slat barriers in 1967–68*

Period and tank type	Losses from tanks at—					
	40 H (check)	3.5 H	7.5 H	10 H	15 H	20 H
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Sept. 9–Oct. 26, 1967:						
Free water	6.5	5.8	5.8	----	----	-----
Lysimeter	3.2	3.5	3.3	4.2	4.2	-----
Apr. 26–Sept. 30, 1968:						
Free water	27.8	25.8	26.4	26.5	28.4	27.6
Lysimeter	14.9	16.7	17.0	15.4	15.0	-----

where the loss was 0.6 inch more than that of the check. The loss at 20 H was close to that of the check. Differences in the effect of the barrier on evaporation and evapotranspiration losses on the south side cannot be explained at this time.

A Canadian report (*4, p. 66*) describes losses from water tanks installed in a wheatfield 200 meters wide, which was protected on the west and east sides by a three-row shelterbelt 5.4 meters high. Water tanks were installed 50 meters from the respective west and east shelterbelts and in the center of the field. Measurements were made from May through September in 1951 and 1952. Winds blew as follows:

From—	*Velocity (m.p.h.)*	*Length of time (percent)*
West	9.9	50
East	9.2	24
Various directions	7.9	26

The average decrease in evaporation during both seasons was 9, 3, and 7 percent for the west, center, and east tanks, respectively. West and east tanks were located at 10 H from the shelterbelts on either side and the center tank was 20 H from both windbreaks.

The average decrease in evaporation from the free-water tanks in 1968 at 3.5, 7.5, 10, and 20 H (table 4) was 10, 9, 8, and 4 percent, respectively. The 8-percent reduction compares to the 9- and 7-percent Canadian reductions and the 4 percent compares to the Canadian 3 percent. The tank at 15 H showed a 12-percent greater loss than the check.

SOIL-WATER BUILDUP

In semiarid areas snowdrifts trapped by windbreaks have an appreciable potential for increasing soil water, which may in turn affect crop yields. Studies since 1961 have shown that only in occasional years was the soil-water buildup from the snowdrifts, present in 7 of the 8 years, sufficient to appreciably increase crop yields. Reasons for the lack of buildup may be traced to (1) the snowfall not coming until after the ground was frozen several feet deep or (2) the usual "January thaw" yielding enough water to later seal the ground surface with ice. Heavy spring runoff occurred when these conditions prevailed.

Willis and others (*5*) studied the gain in soil water and the loss by runoff of water from snowpacks. They found snow-water losses of 90 percent under certain levels of ground soil water and snow cover. The lowest water loss under any soil-water level was 48 percent.

Figure 12 shows the buildup of soil water from snowdrifts on the north and south sides of

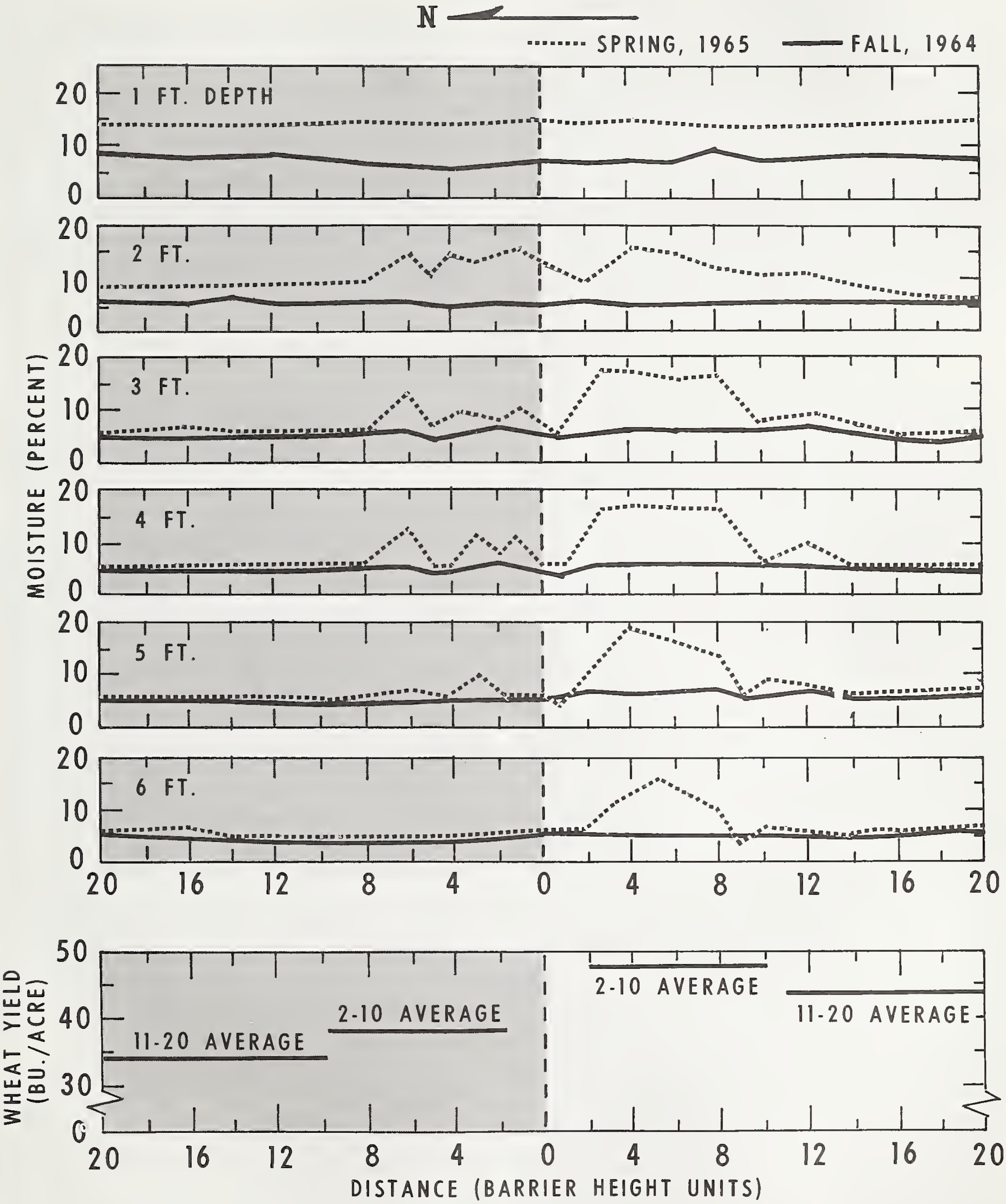

FIGURE 12.—Buildup of soil water from snowdrifts on north and south sides of slat barriers during 1964–65 winter and wheat yields in 1965.

a slat barrier during the winter of 1964–65 and the wheat yields in 1965. The increased yields conformed to the soil-water buildup, which in turn conformed to the snowdrift pattern above ground. Snowmelt water penetrated the soil to a depth of 2 feet over the entire plot. Penetration to a depth of 3 to 6 feet was limited to the 2- to 10-H area on the south side. This area conformed to the snowdrift area above ground. Water penetrated to the fourth foot in the 2- to 8-H area on the north side. Penetration of snowmelt water in other years to depths below 3 feet occurred infrequently, even though snowdrifts contained 15 or more inches of water at thawing time.

The beneficial effect of the snowmelt-water penetration is evident in the yields of the 2- to 10-H area on the south side. Yields on that side were also higher in the 11- to 20-H area, but they cannot be attributed to increased soil water or wind protection. The average wind velocity for the 11- to 20-H area was approximately the same on both sides of the barrier (fig. 6).

CROP YIELDS

Published data (*4, pp. 88–108*) are available showing the effect of tree windbreaks on crop yields. Some data show greatly increased yields on the normal leeward side; other data show little benefit. Stoeckeler (*3*), in summarizing a study of the effect of shelterbelts on crops in the Great Plains, concluded that in Nebraska and Kansas the fields only on the south and east sides of shelterbelts showed substantial benefit. In the Dakotas he found that fields benefited regardless of whether shelterbelts ran north and south or east and west and that the average annual gain in wheat yields over the entire lifespan of the shelterbelt was about 1 bushel per acre. It is possible the Dakota results may be due to the frequent large snowdrifts formed on the north and west as well as the south and east sides of shelterbelts.

A study was made in 1959 to determine the wheat yields on the north and south sides of two noncompetitive slat barriers running in a continuous northeast-southwest direction. The barriers were 12 feet high, with a lower third density of 22 and 14 percent. Wheat was grown on land that had been in bromegrass for several years. Nitrogen and phosphorus fertilizers were drilled with the seed each year. Duplicate soil samples to depths of 6 feet at 1-H intervals were taken each fall and spring to determine the effect of snowdrifts formed by the barriers on building up soil water. Snow depth was measured at 1-H intervals after each snowfall or appreciable movement of snow by wind. Previous data show the barriers had no effect on the precipitation that fell on either side (p. 13).

Table 5 shows wheat yields at various locations on the north and south sides of two slat barriers during 1965–68. Yields were not consistently better on any one side, neither were they always the best on similar sides of the two barriers in any one year. Respective yields per acre over the 4-year period for the 22- and 14-percent barriers averaged 2.3 and 0.9 bushels greater on the south side. The yields per acre for the 14-percent barrier were 2.3 and 0.9 bushels more on the north and south sides, respectively, than for the 22-percent barrier. This greater difference on the north side may be traced to the lower density, which permitted more snow to be blown through the barrier by winds originating on the south side. Yields in 1965 from 16 to 20 H on the north side of one barrier and from 21 to 25 H on the north and south sides of both barriers were omitted owing to heavy grasshopper damage.

Test weights show a small tendency to be heavier near the barriers. Yields from 2 to 10 H show evidence in some years of being greater than those beyond. Increased yields near the barrier can usually be traced to increased soil-water penetration from snowdrifts, which varied greatly from year to year.

TABLE 5.—*Wheat yields at various locations on north and south sides of 2 slat barriers, 1965–68*

Barrier and location (H)	1965				1966				1967				1968				Average			
	North	Test weight	South	Test weight	North	Test weight	South	Test weight	North	Test weight	South	Test weight	North	Test weight	South	Test weight	North	Test weight	South	Test weight
	Bushels per acre	*Pounds*	*Bushels per acre*	*Pounds*	*Bushels per acre*	*Pounds*	*Bushels per acre*	*Pounds*	*Bushels per acre*	*Pounds*	*Bushels per acre*	*Pounds*	*Bushels per acre*	*Pounds*	*Bushels per acre*	*Pounds*	*Bushels per acre*	*Pounds*	*Bushels per acre*	*Pounds*
22-percent barrier:																				
2–5	25.1	-----	28.2	-----	27.1	56	31.1	57	20.6	62	21.4	61	34.6	60	34.7	60	26.8	58	28.8	58
6–10	28.8	-----	31.0	-----	26.0	55	32.8	55	22.6	61	21.6	61	32.4	61	33.6	60	27.5	57	29.8	59
11–15	24.6	-----	25.3	-----	25.0	52	32.6	55	21.9	62	21.8	61	32.9	61	33.8	60	26.1	56	28.4	59
16–20	----	-----	25.1	-----	20.7	51	32.8	55	18.9	61	20.7	61	34.5	60	32.7	60	24.7	56	27.8	59
21–25	----	-----	----------	-----	19.5	53	31.4	55	21.1	61	21.3	60	38.0	61	32.5	60	26.2	58	28.4	58
Average	26.2	-----	{27.4(4) 28.2(3)}	-----	23.7	53	32.1	55	21.0	61	21.4	61	34.5	61	33.5	60	26.3	57	28.6	59
14-percent barrier:																				
2–5	31.0	-----	44.8	-----	30.2	53	27.8	55	21.9	61	19.4	61	38.2	60	36.6	60	30.3	56	32.2	58
6–10	32.6	-----	47.0	-----	31.0	52	28.1	56	20.9	59	21.4	60	35.8	60	37.4	60	30.1	56	33.5	58
11–15	29.7	-----	38.3	-----	27.8	52	24.7	55	18.3	58	17.7	59	35.8	60	33.7	58	27.9	56	28.6	57
16–20	26.4	-----	35.4	-----	25.0	52	26.1	54	21.0	60	16.1	58	34.3	60	35.6	58	27.5	56	28.0	57
21–25	----	-----	----------	-----	27.9	54	27.6	55	20.3	59	17.7	57	33.1	59	31.0	57	27.1	57	25.4	56
Average	29.9	-----	41.9	-----	28.4	53	26.9	55	20.5	59	18.5	59	35.4	60	34.9	59	28.6	56	29.5	57

MEASURES TO REDUCE CROP COMPETITION

Root Cutting

Crops grown close to tree windbreaks sometimes show poorer growth, color, and yield than crops farther away (*4, p. 94*). Figure 13 shows an 85-foot-wide strip of oats on the leeward (south) side of a one-row east-west windbreak. This crop was much poorer in growth, stand, and color than oats farther from the trees. Soil-water determinations to 4-foot depths at heading time showed soil water to be more favorable in the affected than in the normal-colored area. Leaching of nutrients in the snowdrift area may have been responsible for the poorer crop, as the sandy soil permitted ready penetration of water. The assumption of leaching can be supported by the well-known fact that deep-rooted crops, such as alfalfa, seldom suffer from tree competition shown by the shallower rooted grain and corn crops.

Deep furrows are frequently plowed close to the trees to reduce tree-root competition. The furrows show many lateral roots in the top 6 to 9 inches of soil. Roots severed by the plow die on the field side unless they send up aerial shoots. Roots developing aerial growth will continue elongation of growth and competition to crops. Deeper cutting of roots than that possible with a moldboard plow appears necessary if the method is to have favorable results.

Studies to determine what effect root cutting of trees might have on adjacent crop growth were undertaken in 1967, when roots were cut to a depth of 2 feet and 12 feet from the tree

BN-36479

FIGURE 13.—Discoloring of 85-foot-wide strip of oats on leeward (south) side of one-row Siberian elm windbreak indicated leaching of soil nutrients by snowdrifts. Normal color returned to oats beyond end of tree row and on south side of this strip.

row. Cutting was done on both sides of the row in staggered or opposite sections 200 feet long to determine the effect of such treatments on the trees. The work was done in a series of seven east-west one-row shelterbelts, 7 years old. They were composed of Siberian elm, 18 to 20 feet high, spaced 4 feet apart in the row, and combinations of Siberian peashrub, 6 to 8 feet high, with American elm or green ash spaced 3 feet apart in the row. Stands of American elm and green ash were too poor to have any effect on the crop. The sandy soil permitted ready penetration of water and elongation of tree roots in all directions.

Root cutting was done on June 21, 1967, and examinations of the cut roots were made on September 19, 1967, and September 26, 1968. Siberian peashrub roots had not extended to 12 feet in either year. Siberian elm roots had extended beyond 12 feet prior to cutting. Elm roots, varying from fine hairs to over 1 inch in diameter, were found severed in the trench on September 19, 1967, or 3 months after being cut. Most of the roots were in the top 18 inches of soil. Cut roots on the tree side of the trench had formed a callus, behind which up to 45 adventitious roots had initiated new growth. Figure 14 shows new roots coming from behind the calloused cut root. Growth of new roots varied from 3 to over 30 inches in length during the 3 months.

Excavations made on September 26, 1968, or 15 months after the cutting operation, showed heavy branching, averaging in excess of 20 per root behind the calloused cut and extension of these new roots for 6 to 8 feet into the field. Cut roots varied from small to 1½ inches in diameter. On the field side cut roots that developed aerial shoots continued to live. Some extended into the field for 18 feet from the trench, or 30 feet from the parent tree.

Studies of root cutting as an aid to reduce tree competition to crops are insufficient to draw conclusive recommendations at this time. Data indicate that root cutting kills roots on the field side unless aerial shoots develop. On the tree side of the cut, many new roots initiated growth behind the callus and rapidly elongated in sandy soils. Unless cutting is practiced at frequent yearly intervals, the new roots

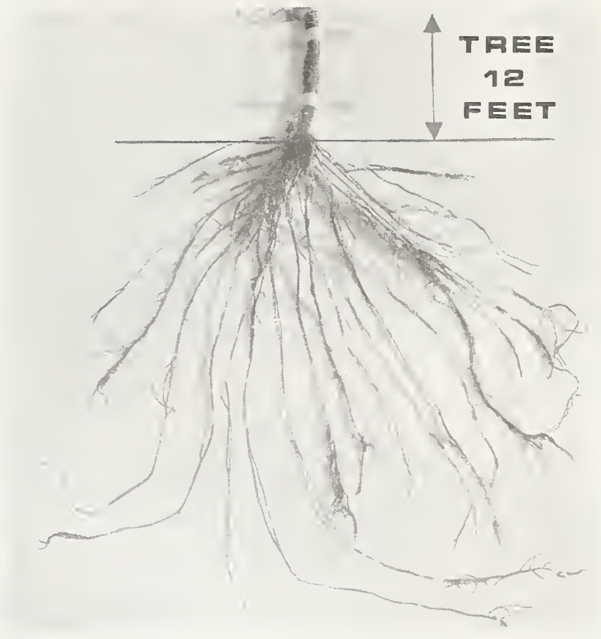

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FIGURE 14.—Siberian elm root, cut off 18 inches below ground surface and 12 feet from parent tree, developed over 40 roots from behind calloused cut.

may offer greater competition than the old ones did before they were cut.

Root pruning at 12 feet from the trees on both sides of the row showed no unfavorable effects on the trees during the first 15 months. For trees such as Siberian elm, which sends shallow roots out for long distances on either side of the row, the frequency and distance from the tree that root cutting is done will probably determine the ultimate effect on tree growth and survival.

Tree Pruning

Removal of lower branches from trees closely spaced in one-row plantings is being widely advocated as a means of reducing row density. Zaylskie (*6*) removed lower branches of Siberian elm to heights of 2.5 and 4.5 feet in one-row windbreaks. The following winter, snowdrifts extended 75 percent farther on the side of pruned trees than of unpruned check trees. The overall width of snowdrifts was in proportion to the degree of pruning, with the widest snow distribution on the side of trees pruned to 4.5 feet.

The wider, shallower snowdrifts behind pruned sections provided supplemental water over a wider area of cropland, reduced the gully-erosion hazard, and did not delay farming operations in the spring for as long as did the unpruned sections. Examinations in 1968 of trees pruned in the fall of 1965 showed many trees had developed new branch growth in the pruned areas that will, unless corrective pruning is carried out, eventually make them more dense in the lower part than before the original pruning.

Tree Thinning

Other studies to reduce density of closely spaced windbreak trees were undertaken in 1967, when every other tree spaced 4 feet apart in an east-west row 1 mile long was pulled out. One 500-foot section was left as a check. The trees were 7 years old and 12 to 15 feet high. They had a winter density of about 55 percent. During the previous three winters this row had formed deep, narrow snowdrifts on one or both sides. These drifts seriously delayed farming operations in the spring.

The first winter after thinning—a winter of below normal snowfall—snowdrifts were 4 feet deep and 50 feet wide on the south side of the unthinned section and 2 feet deep and 150 feet wide on the south side of the thinned section. The field adjacent to the thinned section was ready for farming 3 weeks earlier than the field adjoining the unthinned part.

SUMMARY AND CONCLUSIONS

Studies were made at Mandan, N. Dak., and in the eastern half of this State during 1959–68 on the effects of windbreaks with different tree and shrub species and of slat barriers on wind velocity, snowdrifts to increase soil water, and crop yields.

There were high winds from all directions during this period. Some of the highest velocity winds occurred when cultivated land had no protective cover. Fifty-five percent of the wind originated in an arc extending from south-southwest to north-northeast and 45 percent in an arc from north-northeast to south-southwest.

Tall trees reduced wind velocity on their leeward side for greater distances than did shorter shrubs. Effective wind reduction of 40 percent extended to 10 H.

Series of one-row tree windbreaks at intervals of 20 and 40 rods gave little evidence of cumulative reduction in wind velocity or in trapping snow.

Slat barriers reduced wind velocity at comparable locations approximately the same amount regardless of wind direction. Wind reduction was greater at 5 H on the leeward side of a barrier having 42-percent density in the lower third of its height than behind barriers of 22 and 14 percent. Differences were small at 10 H and approximately the same beyond that point.

High-density windbreaks and barriers created wind turbulence, which reversed wind direction on their leeward side. The turbulence blew all snow off land with no protective ground cover on the leeward side of the windbreak and snowdrift.

Slat barriers had no effect on reducing evapotranspiration from a crop growing in lysimeter tanks on the south side of a barrier. Tanks at 3.5 to 15 H lost more water than the check on the north side. The barrier did reduce evaporation from free-water tanks located adjacent to the lysimeter tanks. Reduction in water loss decreased as distance increased from the barrier.

Yields of wheat grown on the north and south sides of two slat barriers, one of which had a lower third density of 14 percent and the other 22 percent, showed no consistent trends. Average differences were small. The highest yields were on the south side. The barrier with the lower density showed small yield increases compared with the other barrier. When water from snowdrifts trapped by barriers entered the soil, it appreciably increased crop yields in the snowdrift area.

Root cutting of windbreak trees to reduce competition resulted in a big increase from behind the cut of new roots, which grew out

into the field for distances up to 30 inches during a 3-month period.

Removal of lower branches from trees in dense windbreaks to 5 feet above ground gave a much wider snow distribution of less depth on the side of trees pruned to 4.5 feet. New regrowth in 3 years following the pruning indicated the trees might eventually develop a denser growth than if they had not been pruned.

Removal of every other tree in closely planted windbreak rows has given more promise of spreading snow over wider areas of cropland, reducing the water-erosion potential, and permitting earlier working of the land than has any other method. Improved planting practices now being used of spacing trees and shrubs farther apart in the row will solve many of the problems confronting farmers who have high-density windbreaks.

LITERATURE CITED

(1) George, E. J., Broberg, D., and Worthington, E. L.
1963. INFLUENCE OF VARIOUS TYPES OF FIELD WINDBREAKS ON REDUCING WIND VELOCITIES AND DEPOSITING SNOW. Jour. Forestry 61 (5): 345–349.

(2) Hetzler, R. E., Willis, W. O., and George, E. J.
1967. CUP ANEMOMETER BEHAVIOR WITH RESPECT TO ATTACK ANGLE VARIATION OF THE RELATIVE WIND. Amer. Soc. Agr. Engin. Trans. 10: 376–377.

(3) Stoeckeler, J. H.
1962. SHELTERBELT INFLUENCE ON GREAT PLAINS FIELD ENVIRONMENT AND CROPS. U.S. Dept. Agr. Prod. Res. Rpt. 62, 26 pp.

(4) Van Eimern, J., Karschon, R., Razumova, L. A., and Robertson, G. W.
1964. WINDBREAKS AND SHELTERBELTS. Tech. Note No. 59, WMO-No. 147, 70 TP, 188 pp. Geneva, Switzerland.

(5) Willis, W. O., Carlson, C. W., Alessi, J., and Haas, H. J.
1961. DEPTH OF FREEZING AND SPRING RUNOFF AS RELATED TO FALL SOIL MOISTURE LEVEL. Canad. Jour. Soil Sci. 41: 115–123.

(6) Zaylskie, J. J.
1967. MODIFIED WINDBREAKS CONTROL WIND, SNOW DRIFT. N. Dak. Farm Res. Bimo. Bul. 23 (10): 4–6.

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